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It is shown that it is possible to design an electrically small inductive-loaded planar antenna, with a matching post, that is matched to a 50-ohm coaxial line. Planar antennas having a wide range of configurations were simulated at UHF. Many of these antennas performed very well. Three antennas having the best performance were simulated, fabricated and measured. The antennas had shapes that varied from a square of about 5 cm on a side to a low profile shape 3 cm in height and 9 cm in length. The electrical heights of these antennas ranged from0.055 λ down to 0.035 λ. All antennas were elliptically polarized and had simulated maximum gains of about 4.4 dBi along the horizon and about 10 dBi lower at zenith. These antennas are very high Q so the bandwidths were only about 1% for a Voltage Standing Wave ratio (VSWR) below 2.0. The electrical size of the antenna can be further reduced by placing a dielectric slab between the antenna elements. It is shown that it is possible to electrically tune the frequency of the antenna, by placing a variable capacitance in series with the inductance, thus increasing the bandwidth. The agreement of measurements with simulations was excellent.

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AN ELECTRICALLY SMALL INDUCTIVE-LOADED PLANAR ANTENNA

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15 April 2006 to 31 January 2009

In-House Report

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An Electrically Small Inductive-Loaded Planar Antenna

Abstract

It is shown that it is possible to design an electrically small inductive-loaded planar antenna, with a matching post, that is matched to a 50-ohm coaxial line. Planar antennas having a wide range of configurations were simulated at UHF. Many of these antennas performed very well. Three antennas having the best performance were simulated, fabricated and measured. The antennas had shapes that varied from a square of about 5 cm on a side to a low profile shape 3 cm in height and 9 cm in length. The electrical heights of these antennas ranged from 0.055 λ down to 0.035 λ. All antennas were elliptically polarized and had simulated maximum gains of about 4.4 dBi along the horizon and about 10 dBi lower at zenith. These antennas are very high Q so the bandwidths were only about 1% for a Voltage Standing Wave ratio (VSWR) below 2.0. The electrical size of the ntenna can be further reduced by placing a dielectric slab between the antenna elements. It is shown that it is possible to electrically tune the frequency of the antenna, by placing a variable capacitance in series with the inductance, thus increasing the bandwidth. The agreement of measurements with simulations was excellent.

Index Terms- **Electrically small planar antennas, impedance matching, inductive loaded antennas, inverted-F antenna**

1.0 Introduction

Electrically small antennas generally have a low radiation resistance and a high reactance, thus making it difficult to transfer power to the antenna. It has been shown that it is possible to match an electrically small antenna to a 50-ohm coaxial line by placing a matching post near the base of the antenna [1, 2, 3]. This previous antenna was designed to fit in a cubical volume. In this investigation we design a planar antenna, which is also electrically small, self-resonant and is matched to a 50-ohm coaxial line; it is mounted over a ground plane. Since it has a planar configuration it can be used for closely spaced array elements. This antenna is actually a modification of an inverted – F antenna, where an extra set of parallel wires is added to that antenna [1]. The extra length of folded wires allows this antenna to be electrically small, which is not the case for the conventional inverted - F or other transmission line antennas [4]. In order to achieve the matching, we place an inductance at its endpoint and use a matching post near the input of the antenna, both of which are connected to the ground plane. We conducted simulations of the antenna configuration shown in Fig. 1, varying antenna length, l, width, w, total height above the ground plane, h, height of the horizontal connecting wire above the ground plane, h_2, height of the matching post above the ground plane, $h_{1,}$ the angle that it makes with the vertical segment, α and the inductance, L. After obtaining satisfactory computational results, we built and tested three of these antennas. We show the computed and measured impedance plots and the simulated radiation patterns. We also show that the operational frequency can be further lowered by inserting a Teflon slab between the wires. In addition we place a capacitor in series with the inductor and show that the operational frequency can be changed by varying this

capacitance; thus it should be possible to tune this antenna electronically by using a varactor to provide the variable capacitance.

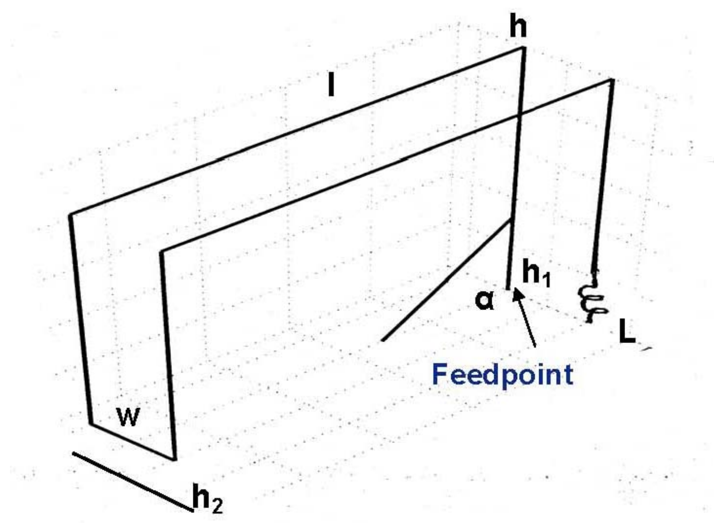

Figure 1. A sketch of the planar antenna.

2.0 Approach

The antenna simulations, which used the Numerical Electromagnetics Code (NEC-4) [5], were initially done for values of antenna length, l and height, h fixed at 5 cm. The height of the matching post, h_1 was varied from 0.4 cm to 1.2 cm, and its angle, α, for values of 30º, 45º and 60º. The height h_2, was varied from 1 cm to 3 cm, the width, w from 0.5 cm to 2.0 cm and the inductance, L, from 0.1 to 1.0 μHenries. The objective was to find antenna configurations that had a low VSWR when driven from a 50-ohm coaxial line. We did not attempt to optimize the radiation pattern since small antennas over a ground plane tend to have near hemispherical coverage. We analyzed an antenna having the following values: l = 5 cm, h = 5 cm, w = 1 cm, h_1 = 1 cm, h_2 = 1 cm and α = 30º and L = 0.55 μHenries; the wire diameter was 3/32” (0.24 cm) the simulation was done for the antenna over an infinite ground plane. The input impedance, VSWR and radiation pattern were computed. We then built this antenna using 3/32” brass tubing and a wire-wound inductance about 1 cm in length, 0.4 cm in diameter and having a value of 0.55 μHenries; since the dimensions of the fabricated antenna were slightly different from the original simulation, we redid the simulation using the dimensions of the antenna that was built. We also simulated and tested lower profile antennas having approximate lengths, l = 7 cm and 9 cm, and heights h = 4 cm and 3 cm respectively. Once again, since the fabricated antennas did not have the same exact dimensions as the original simulation we redid these simulations with dimensions that were close to those of the fabricated antennas. The measurements were made with a Hewlett- Packard Model 8510 Network Analyzer with the antenna mounted over a 4ft x 4 ft (1.2 m x 1.2 m) ground plane. The antennas were fed with a Type N connector.

3.0 Results

In Fig. 2 we show the results of the initial simulations. The operational frequency is plotted as a function of inductance for antenna widths of 0.5, 1.0, 1.5 and 2.0 cm. The VSWRs associated with these curves were typically under 2.0. We note that the operational frequency decreases sharply as the inductance is increased and then tends to level off. Also, the frequency decreases as the antenna width is increased; this is expected since the larger width produces a larger antenna and thus a lower frequency.

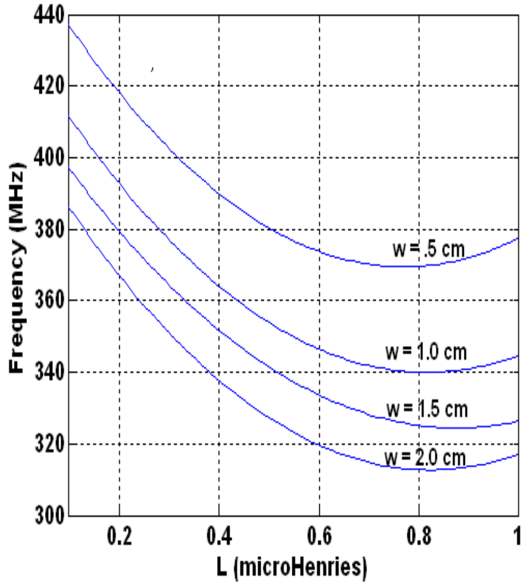

Figure 2. A plot of the simulated operational frequency as a function of terminal inductance for four antenna widths.

In Fig. 3 we show simulated and measured impedance plots for a planar antenna having the following dimensions: l = 6.5 cm, h = 5.1 cm, w = 1.1 cm, h_1 = 3.4 cm, h_2 =1.1 cm, α = 69º and L = 0.55 μHenries. The solid curve is the simulated antenna and covers the frequency range from 320 MHz to 331 MHz. A minimum VSWR of 1.10 occurs at a frequency of 325 MHz. The dashed curve is the measured impedance and covers the frequency range from 316 MHz to 325 MHz. A minimum VSWR of 1.16 occurs at a frequency of 321 MHz. The electrical height of this antenna is only 0.055 λ; the total length of tubing is about 0.41λ. The approximate frequency band for which the VSWR is below 2.0 is 1.1% for the simulation and 1.5% for the measurement.

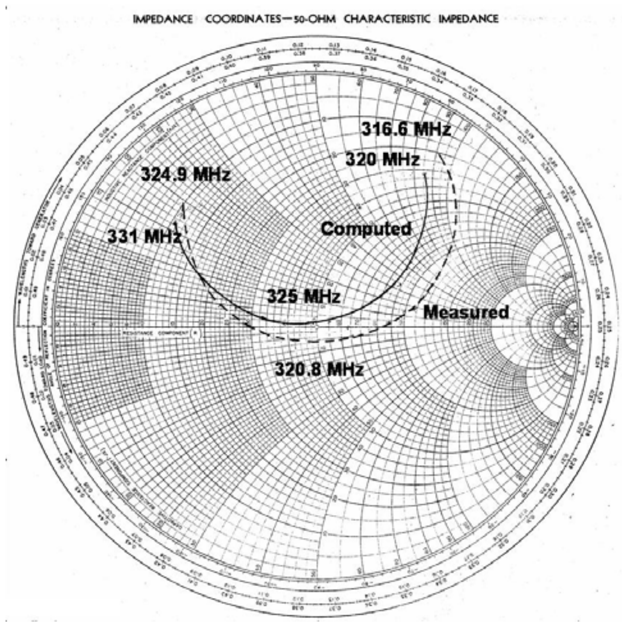

Figure 3. Simulated and measured impedance plots for a planar antenna with l = 6.5 cm, h = 5.1 cm and w = 1.1 cm

In Fig. 4 we show the simulated radiation pattern of this antenna. As for all electrically small antennas over a ground plane, we have near hemispherical coverage. Since this antenna has both vertical and horizontal wires, we have vertical polarization at the low elevation angles, horizontal polarization at zenith and elliptical polarization at the intermediate angles. The maximum vertically polarized gain is about 4.3 dBi along the horizon and the horizontally polarized gain in the zenith direction is about -7 dBi.

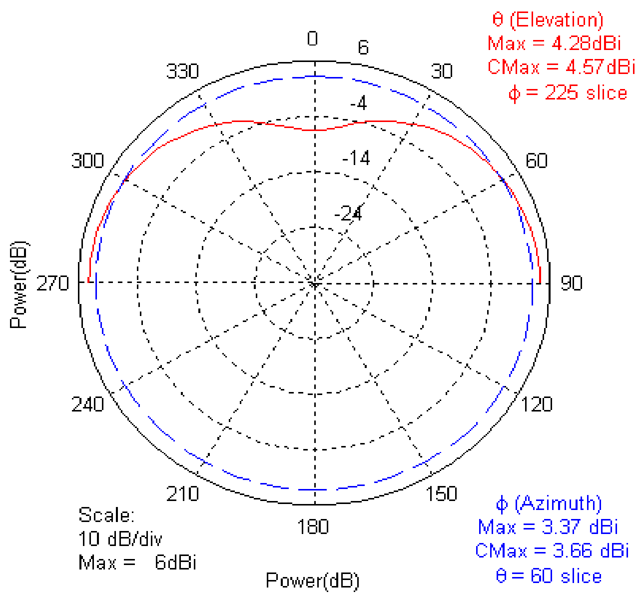

Figure 4. Simulated 2-D pattern for planar antenna with l = 6.5 cm, h = 5.1 cm, w = 1.0 cm.

In Fig. 5 we show simulated and measured impedance plots for a planar antenna having the following dimensions: l = 7.15 cm, h = 4.1 cm, w = 1.15 cm, h_1 = 2.0 cm, h_2 =1.1 cm, α = 53º and L = 0.55 μHenries. The solid curve is the simulated antenna and covers the frequency range from 345 MHz to 355 MHz. A minimum VSWR of 1.23 occurs at a frequency of 349 MHz. The dashed curve is the measured impedance and covers the frequency range from 355 MHz to 362 MHz. A minimum VSWR of 1.22 occurs at a frequency of 359 MHz. The electrical height of this antenna is 0.048 λ; the total length of tubing is about 0.38λ. The approximate frequency band for which the VSWR is below 2.0 is 0.8% for the simulation and 0.9% for the measurement. The radiation pattern of this antenna is similar to the previous antenna but has a slightly higher gain at zenith.

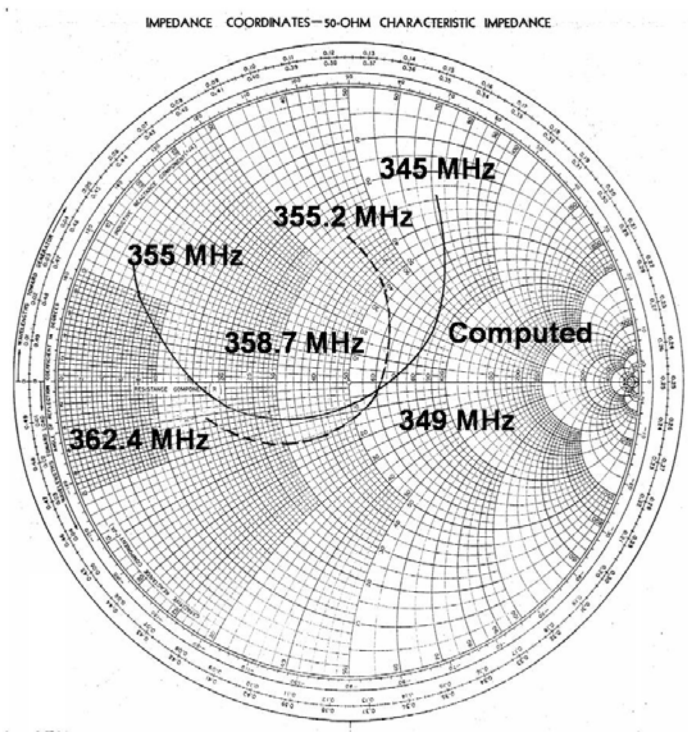

Figure 5. Simulated and measured impedance plots for a planar antenna with l = 7.1 cm, h = 4.1 cm and w = 1.15 cm.

In Fig. 6 we show simulated and measured impedance plots for a still lower profile planar antenna having the following dimensions: l = 9.1 cm, h = 3.0 cm, w = 0.7 cm, h_1 = 1.4 cm, h_2 =0.4 cm, α = 49º and L = 0.55 μHenries. The solid curve is the simulated antenna and covers the frequency range from 350 MHz to 357 MHz. A minimum VSWR of 1.29 occurs at a frequency of 354 MHz. The dashed curve is the measured impedance and covers the frequency range from 351 MHz to 357 MHz. A minimum VSWR of 1.04 occurs at a frequency of 354 MHz. The electrical height of this antenna is 0.035λ; the total length of the tubing is about 0.38λ. The approximate frequency band for which the VSWR is below 2.0 is 0.4% for the simulation and

1.0% for the measurement. Once again the radiation pattern of this antenna is similar to those of the previous antennas and as expected, because it has longer horizontal segments, the gain in the zenith direction is higher.

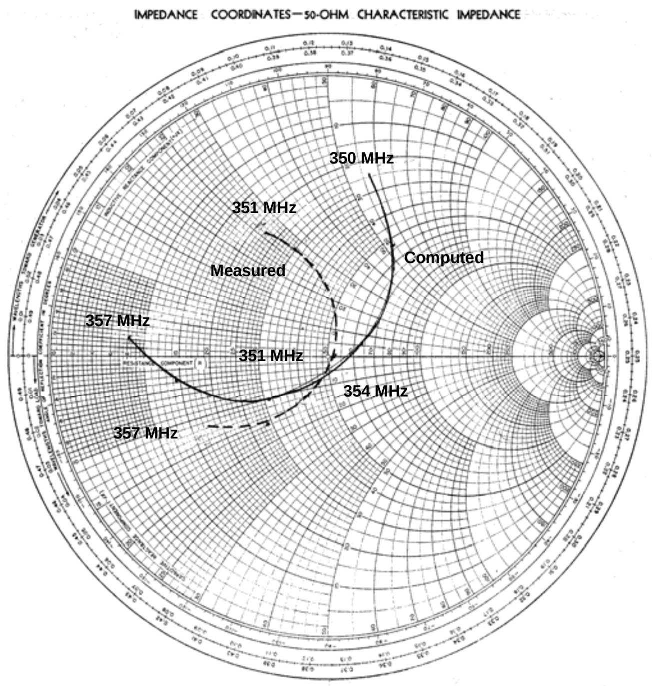

Figure 6. Simulated and measured impedance plots for a planar antenna with l = 9.1 cm, h = 3.0 cm and w = 0.7 cm.

We then inserted a slab of teflon, with dielectric constant of 2.1 and loss tangent of 0.0002 in an electrically small planar antenna of length 5 cm, height 5 cm and width 1 cm. The insertion of the dielectric should reduce the operational frequency of the antenna. In Fig.7 we plot the measured impedance of this antenna with and without the teflon insert. We see that the operational frequency has dropped from 350.4 MHz to 332.0 MHz, a change of about 5%.

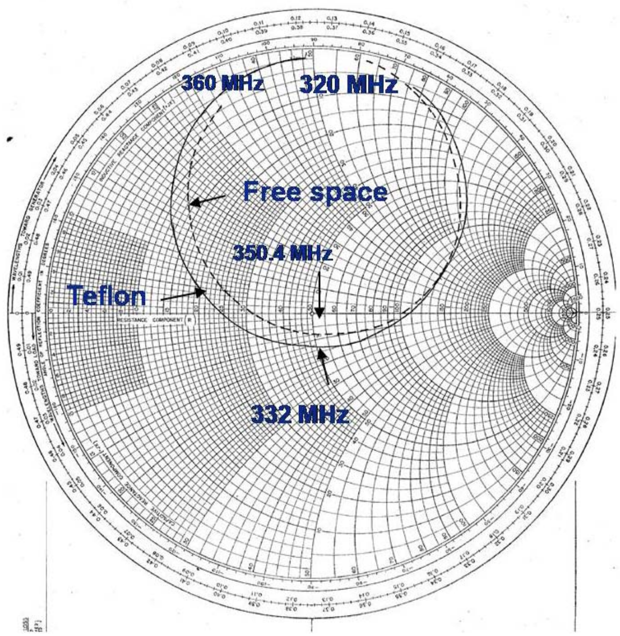

Figure 7. Fabricated planar antenna with and without teflon insert for
l = 6.5 cm, h = 5.1 cm, and w = 1.0 cm

The planar antenna terminated with an inductance is narrow band. The optimum frequency can be changed by varying the inductance; however this cannot be easily done electronically. However, it should be possible to vary the frequency by using a voltage-controlled capacitor (varactor). Initially, a simulation was done for a planar antenna of l = 5 cm, h = 5 cm, w = 0.5 cm, h_1 = 1 cm, h_2 = 1 cm and $\alpha = 30^o$ and L = 0.55 μHenries. A set of capacitances having values of 0.3, 0.4, 0.5, 1.0 and 2.0 x 10^{-12} F were placed in series with the inductance. The impedance plots are shown in Fig.8. It is seen that as the capacitance is increased, the antenna can operate over lower frequency bands, thus increasing its bandwidth.

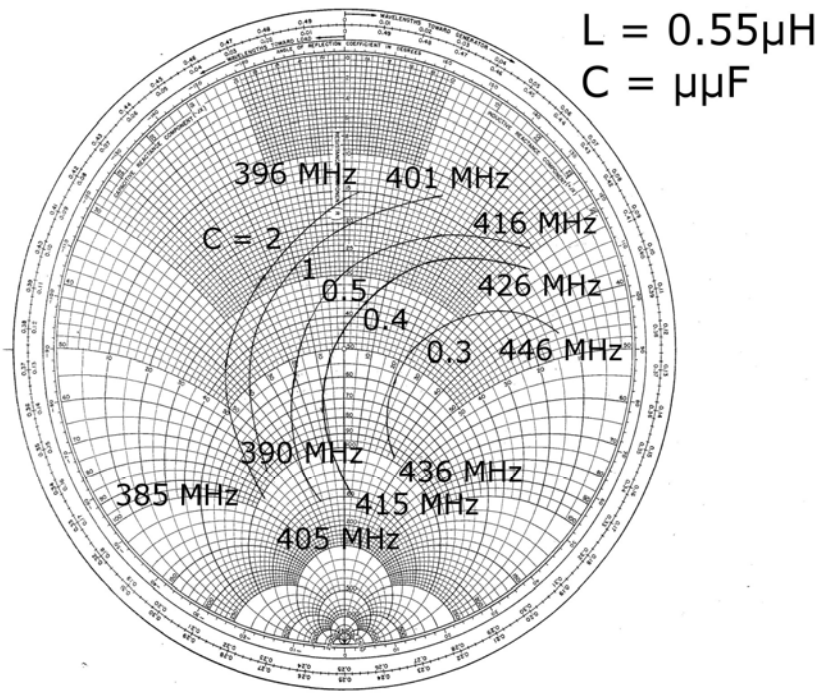

Figure 8. Planar antenna with a fixed inductance and variable capacitance

4.0 Conclusions

We have shown that it is possible to design and fabricate an electrically small inductive loaded planar antenna that is very well matched to a 50-ohm coaxial line. There is excellent agreement between simulated and measured results considering that the simulation is done for the antenna over an infinite ground plane and with a "point source" inductance, whereas the measurements are made over a finite ground plane with an inductance having a finite size. Also, the fabricated antenna is not identical to the simulated antenna.

This configuration is applicable as an array element, since it has a narrow width, thus allowing the elements to be closely spaced. The design parameters are flexible from the standpoint that the planar shape can vary in length, height and width. As is the case for small antennas, these antennas are relatively narrow band, having a bandwidth of approximately 1% over the band for which the VSWR is below 2.0. If the antenna is made larger, the bandwidth can be further increased. The antenna may be made physically smaller if a dielectric slab is inserted between the parallel wires. Also it may be possible to fabricate this antenna on printed circuit board and replace the wire-wound inductor with a smaller surface mount inductor. Finally, the bandwidth of this antenna may be extended by inserting a varactor in series with inductance at the termination.

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